Chapter

Internet Connectivity in Building Interiors: Architecture and Sustainability Considerations

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Abstract

This paper addresses the issue of connectivity and its relationship to the architecture of spaces. The internet of things and wifi technology is coming into the forefront of lifestyles in present times. We tend to spend much of our life activities using devices that need internet connectivity, wifi coverage, both indoors and outdoors. The technology behind it is also in the process of shifting gears, from 3G to 4G to 5G soon. However questions arise: How suitable are existing buildings for the sorts of internet technology that are predicted for the future? And how can the coverage and connectivity issue be addressed to give greater efficiency to new buildings? Will we require greater open layouts that give more visual connectivity within interior spaces to permit efficient connectivity between routers, boosters and appliances? The expertise of both Architects who design spaces, as well as RF Engineers who are responsible for setting up the internet systems within the spaces are involved in efficiently handling these queries. The paper incorporates recent studies have revealed that certain building materials may be more suited to Wifi penetration, while others act in a more opaque way. Architects are the main decision-makers regarding the final choice of such questions, but they have very little grounding in the technicalities involved related to connectivity issues. It is important to have them focus on these questions and seek answers through multi-disciplinary forums, thus also to deepen collaboration between the related professionals, in order to create more Wifi connectivity in building interiors. From the user perspective, this is a vital need, as the user of today spends enormous amounts of time at these electronic, computing devices that require uninterrupted and quality connectivity. It thus also becomes a question of sustainability.

Keywords: wifi connectivity, architecture, propagation losses, sustainability, multi-disciplinary approaches

1. Introduction

This book discusses issues about emerging technologies and the computing industry, and the focus of this chapter is on internet connectivity within building interiors. The chapter begins with a background on the needs for such connectivity, why Architects need to be concerned with such technical matters, and the need for a multi-disciplinary approach to the issue. It then elaborates on some of the key concepts of connectivity that affect the architecture of spaces, extracting from a study done by the authors, to determine building interior components that affect connectivity, impacting propagation of radio waves. The results of the study point to certain interior features and their design, to increase efficiency of the system, and minimize propagation losses.

In the discussion, conflicts, between best design scenarios focused on the connectivity issue, and satisfaction of other demands on internal spaces, are revealed. The field is still very new, as development in internet connection and propagation is progressing exponentially, with improvements taking place almost continuously. And if there is a gap in the transfer of knowledge, regarding what is required for good propagation, and what is being designed to house these systems, there is likely to be a clash of intentions, resulting in inefficient systems, and reduced user satisfaction. It is the intention of the authors, through this chapter to bring awareness to these inter-related issues, and to the need for collaboration, between the different professionals designing and implementing the spaces, on the one hand, and the systems, on the other.

In a nutshell, the chapter addresses the issue of the Internet of Things (IoT), wireless connectivity and related issues, as affected by the architecture of built spaces. Based on a recent study completed at BUET on the subject, and on related research, the issues are looked at broadly, from an architectural point of view, and steps that need to be addressed immediately to resolve these, are touched on, with suggested guidelines.

2. Lifestyle changes and need for connectivity

There has been a major shift in lifestyles caused by the Fourth Industrial Revolution (4IR). This revolution can be defined as a new chapter in human development, built on the previous three industrial revolutions that had shaped life since the mid-eighteenth century onwards: the first developing from water/steam power, the second from electric power, just before the beginning of the twentieth century, and the third building on developments in electronics and information technology, in the second half of the twentieth century [1].

This fourth revolution, begun at the turn of this century, has been enabled by extraordinary technological advances, superseding the three preceding development phases, and here we see a fusion of technology, which blurs the lines between the physical, digital and biological spheres. This affects the way that the world is developing in three ways – the speed/pace (exponential) at which changes take place, the scope of the changes (due to unprecedented processing power, access to knowledge, artificial intelligence, blurring of boundaries, digital, nanotechnology, material science, etc), and the impact of the systems (on production, management and governance). And from the point of view of life, this fourth industrial revolution has completely changed the lifestyle of humans. Those who can take advantage of this revolution are the ones that will see progress, others will lag behind. And the scale of the gap will increase incrementally, given the tremendous force and interconnectivity of the phenomenon.

The 4IR has ensured the passage of the internet of things and wireless technology into the forefront of life activities nowadays. The profusion of internet and information technology has led people to spend more and more time at their computers, smart devices and cell phones, spending their work time using these, and their leisure time enjoying them. Smart devices are used for functions ranging from communication, both officially and socially, to shopping, internationally and locally, to virtual meetings and social media, and has likewise extended to virtual education and training. This changed behavior has led the media to refer to today's youth as the 'indoor' generation, and research finds that around

90 percent of people spend close to 22 hours indoors each day in the developed world [2], at the present time.

Throughout history, people have tried to adapt Indoor conditions to suit their needs, and based them on their available resources and know-how. But the needs, as well as available knowledge base, have now changed very rapidly, and it is becoming important to examine how suited today's built spaces are, to accommodate these new needs, given the technology available to us. There are two major avenues of investigation here: whether the buildings allow proper conditions needed for such exchanges and activities, and whether the buildings can protect humans from any adverse effects of these exchanges.

Moreover, the technology behind the internet of things, is also in the process of shifting gears, from 3G to the present 4G, which is being upgraded to 5G soon. Up until now, this domain has been dominated only by RF (Radio Frequency) engineers, those who focus their expertise on the propagation of radio waves, and on their efficient and seamless transmission. RF Engineers work on improvement of the performance of wireless communication, by ensuring good RF signal strength at the receiver [3]. The need for Architects to be involved in these considerations is paramount at the moment, as it is they who are primarily responsible for designing and shaping the built environment, where all this propagation is to take place. They are the ones who will be ascertaining the arrival and receipt of any propagation, and thereby the success of such connectivity issues.

3. The building Internet of things (BIoT)

The Internet of Things (IoT) is expanding exponentially, with improvements in connectivity and the related technology. It is now an important instrument, in the process used to communicate with society, and is thus increasing the participatory approach to a myriad of things. This phenomenon is driving much of human activity, and is one of the most compelling factors that are making humans into sedentary beings, focussed solely on indoor living. When considered within buildings themselves, this phenomenon is termed BIoT, or Building Internet of Things (BIoT).

Another important innovation of recent times, is related to connectivity of equipment within 'smart' buildings, i.e. buildings having automated solutions for security, safety, energy management, comfort, entertainment, health, and so forth, all dependent on machine to machine (M2M) communication. This too is now becoming an integral part of BIoT and daily living, and occupants now depend on smart solutions within buildings, to ensure much that was previously under the domain of behavioral response, like adjusting window openings for thermal comfort, or controlling lighting level manually or using curtains and so on. In a smart building, service robots, and other devices for desired control, can be programmed to perform many of these activities, using 4G or 5G platforms, as indicated in **Figure 1** [4].

Recent studies have revealed that certain building materials and their properties may be more suited to wireless signal penetration, while others are relatively opaque. Since Architects are the main decision-makers, regarding the final choice of such questions as above, while they have very little grounding in the technicalities involved, it is important to have them reflect on such questions, and seek answers through multi-disciplinary forums, thus also to deepen collaboration between the related professionals, in order to create more wireless connectivity in building interiors. From the user perspective, this is a vital need, as the user of today spends enormous amounts of time at these electronic, computing devices that require

Figure 1.
Automated devices using 4G or 5G platform in smart buildings [4].

uninterrupted and quality connectivity. It is seen, therefore, that the performance of wireless communication is finding more direct bearing on the satisfaction level of users of the building, contributing thus to both their performance, as well as user comfort, above and over issues of comfort in terms of other environmental variables. It is becoming increasingly important now, to initiate studies on this aspect of comfort, as an added dimension of evaluating building performance, in a way that was in the past studied with reference to thermal and visual comfort issues.

4. The question of sustainability

In addition to the above considerations, any building activity or development today must be sustainable, and the business-as-usual model comes with inherent risks to the planet and continued human existence. This requires us to look at the issue in several separate dimensions. As buildings are one of the highest consumers of electricity, and Architects are largely responsible for their design, it is imperative that they be conversant with all the pathways in which energy efficiency can be achieved in buildings. Good internet connectivity within buildings too, is directly affected by the design of buildings. It, therefore, becomes incumbent to look at whether the satisfaction of these two requirements, for connectivity, and for efficiency, cause contradictory physical manifestations in building design.

Sustainability, considering the internet issue, can thus be approached, through an examination of connectivity needs, and any potential conflicts that they present, with other human and environment related issues. This involves studying the main linkages, synergies, and trade-offs with other issues, e.g. of health, comfort and productivity, bio-diversity, etc. As the issue of sustainability is intrinsically related to acceptance by user groups, it is also important to examine connectivity "solutions" available to the public and private sectors, their desirability, acceptance, affordability and other such factors, so that whatever solution is adopted for a building is inclusive, does not increase divides between different groups. This human factor is also one of the key indicators of sustainability.

5. SDGs, internet connectivity and architecture

A short discussion on the UN sustainable development goals (SDGs) set up in 2015, and the intrinsic interlink with the world-wide-web and internet connectivity is given below. If the spaces that serve such connectivity are not designed with seamless connectivity in view, there is no doubt that it will not be possible to achieve these goals. SDGs require that governments, private sector, civil society and citizens should partner together, aiming for a better planet for future generations [5]. And the road map to achieve this, banks largely on incorporating creativity, know-how, technology and financial resources available.

Goals 1 and 2 relate to deprived populations; no poverty and zero hunger. Much of poverty arises due to lack of opportunities, which is a direct result of not having proper access to available options of employment, business outlets, and so on. Clearly, these goals are interconnected, and cannot be tackled in isolation. Information exchange is vital, populations require to be connected through cell phones, etc. Goals 3 and 4, regarding health and education, are likewise related to connectivity. Proper monitoring, access, etc. are all dependent, on how easily information can be transferred from place to place, in order to stem problems at source. The internet is vital for present-day education, which can serve to be a tool, tackling the lack of libraries and information. Goal 8, decent work and economic growth, and Goal 9, industry, innovation and infrastructure, and again depend on increased connectivity, and the related issue of spaces and their design.

Goal 11 is directly about cities and thus architecture, and the way the built environment impacts our planet. The design of cities and urban areas affects the passage of internet connectivity, due to building positioning, spacing, material use and so forth, and thus decisions that impact these, are the direct concern of all the related professionals being discussed here.

Goal 12 relates to responsible consumption and production, and is also heavily dependent on internet availability. Connectivity within groups is vital to any business activity, therefore, the spaces where people produce, i.e. industries, and their design are vital in meeting this goal. Consumption is part and parcel of everyday living, and sustainable practices call for reduction, reuse and recycling, i.e. circular economies. Again connectivity is vital, to ensure that the system works properly and promptly, to avoid clogs and blockages within the flow.

Goal 13, is to control climate change. This is all pervasive, requiring attention to the design of built spaces, which is largely responsible for the carbon footprint and the consumption of resources on our planet. Buildings designed to conserve energy and use natural resources are important, just as are automated systems within buildings, which can monitor variables, and largely offset much waste of energy, and maintain the efficiency of systems. Such systems again cannot function without internet connectivity.

Goals 16 and 17 relate to people's issues and their participation. Connectivity and platforms for voicing opinions are imperative to achieve these, making the internet and spaces of use directly related to their success.

The above points have been raised, to underline the importance of treating the issue of connectivity as a key part of architecture considerations, and to the attainment of many of the SDGs. The need for the professionals to collaborate in the design of buildings, and spaces in between, is clear from these parallel associations.

6. Research relating architecture with RF matters

Architects, through their training, look at challenges existing in a given situation, and on means to address them through holistic solutions. Till recently, environmental forces were largely natural, but since the age of the information technology, the profusion of high frequency propagation has introduced a new dimension to ensure proper functioning, and with it are related health issues. The problem has been under the sole jurisdiction of Radio Frequency (RF) Engineers, who specialize in devices and transmission using and operating on radio waves, i.e. wireless devices like mobiles, which are largely becoming the centre of existence of modern lifestyles. But research shows that the efficiency of RF transmissions and reception, seems to be intrinsically associated with the design of spaces. It is therefore becoming imperative that Architects work hand-in-hand with RF Engineers, to create environments that are conducive to proper utilization of available RF regimes, to ease unnecessary losses, which can result in poor connectivity and energy inefficiency. This section summarizes a study done at BUET [6] and its follow up, to investigate the issue of internet connectivity and its connection to architecture.

6.1 Options for wireless service

The first point highlighted in the study is that building occupants are now demanding increasingly higher data rate, as new applications are emerging. Examples of these are: Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), and Extended Reality (XR). The global mobile data traffic is expected to increase from 19.01 exabytes per month in 2018 to 77.5 exabytes per month by 2022, at an annual growth rate of 46 percent [7].

The wireless connectivity in the building can be supported by many different technologies, as shown below.

1. Long Range High/Moderate Power: 3G/4G/5G cellular system.
    - For IoT devices, Narrowband-IoT (NB-IoT) or Extended Coverage GSM (EC-GSM) can be used.
    - In-Building Solutions (IBS): femtocells, picocells and Distributed Antenna System (DAS)
2. *Short Range High Speed:* Wi-Fi. For IoT devices, a version, called Wi-Fi HaLow (IEEE 802.11ah), with lower power consumption, has been introduced.
3. *Short Range Moderate Speed:* Wireless Personal Area Network (WPAN)
    - Bluetooth and BLE (Bluetooth Low Energy): Originally, standardized as IEEE 802.15.1 for operation in ISM radio bands.
    - ZigBee: Standardized as IEEE 802.15.4 for operation in ISM radio bands.
    - Thread: An IPv6-based, low-power mesh networking technology for IoT products.
    - Z-Wave: A low-power mesh networking technology, primarily used for home automation.
4. Long *Range Low Power:* Low Power Wide Area Networks (LPWAN)
    - Sigfox: A global cellular based network operator that supports IoT products at low-power.

- LoRa: A cellular based technology that supports IoT products at low-power.

- Waviot: A wireless technology that uses low-power and primarily, supports electricity meters and water meters.

- Ingenu: A provider of wireless networks that supports IoT products at low-power.

- Weightless: A set of open wireless technology standards that supports IoT products at low-power.

The chosen option for any particular building, will be affected by the geometry of the space, and its material quality. Therefore, contributions from architects can ease the job, towards ensuring proper wireless coverage and connectivity. Architects and RF engineers can complement each other, to address the growing challenge better. Green architecture considerations, apart from the physical features of the built spaces, can incorporate suggestions for various other measures, for example, solar panels, thermal mass building construction, green materials, including wood, stone, or earth, recycled waste materials, and so forth.

Architectural intervention can improve wireless signal coverage, by ensuring maximum signal power, minimizing interference to its path. Such intervention is significant, since the building will undoubtedly last much more than a few decades, and should thus be ready for the rapid changes that are predicted in the wireless support arena. However, there has not been enough engagement of architects in this area so far, and mostly, analytical discussions have been made in this regard [8], restricted within RF engineering circles, often beyond the knowledge of Architects.

6.2 Shifting gears: from 4G to 5G

4G has changed the life of people, but 5G is set to change society in its entirety. While the key focus of the developers for generations up to 4G, has been to improve data rate support, 5G has an additional focus, which is to support numerous use cases, with diverse technological requirements. These use cases are categorized with three basic types of requirements as shown below [9], all of which are seeing increasing applicability in new urban paradigms:

1. *Enhanced Mobile Broadband (eMBB):* The basic requirement of the eMBB use cases is very high data rate and its examples are, live HD videos, VR, and AR.

2. *Massive Machine-Type Communications (mMTC):* The basic requirement of the mMTC use cases is massive density of user devices, with each requiring very low data rates. Its example is Internet of Things (IoT) devices.

3. *Ultra-reliable low-latency communication (URLLC):* The basic requirements of the URLLC use cases are very low latency and very high reliability. Its examples are vehicular communication and automation in the industries.

The categorization of various use cases towards the three classes for 5G is illustrated in **Figure 2** [9].

Another complication in wireless connectivity, arises from the rapid changes taking place in the related technology. Due to the exponential growth of internet use, the lower frequencies of propagation are getting saturated. Service providers have incrementally shifted from 2G to 3G to 4G in the space of fewer than

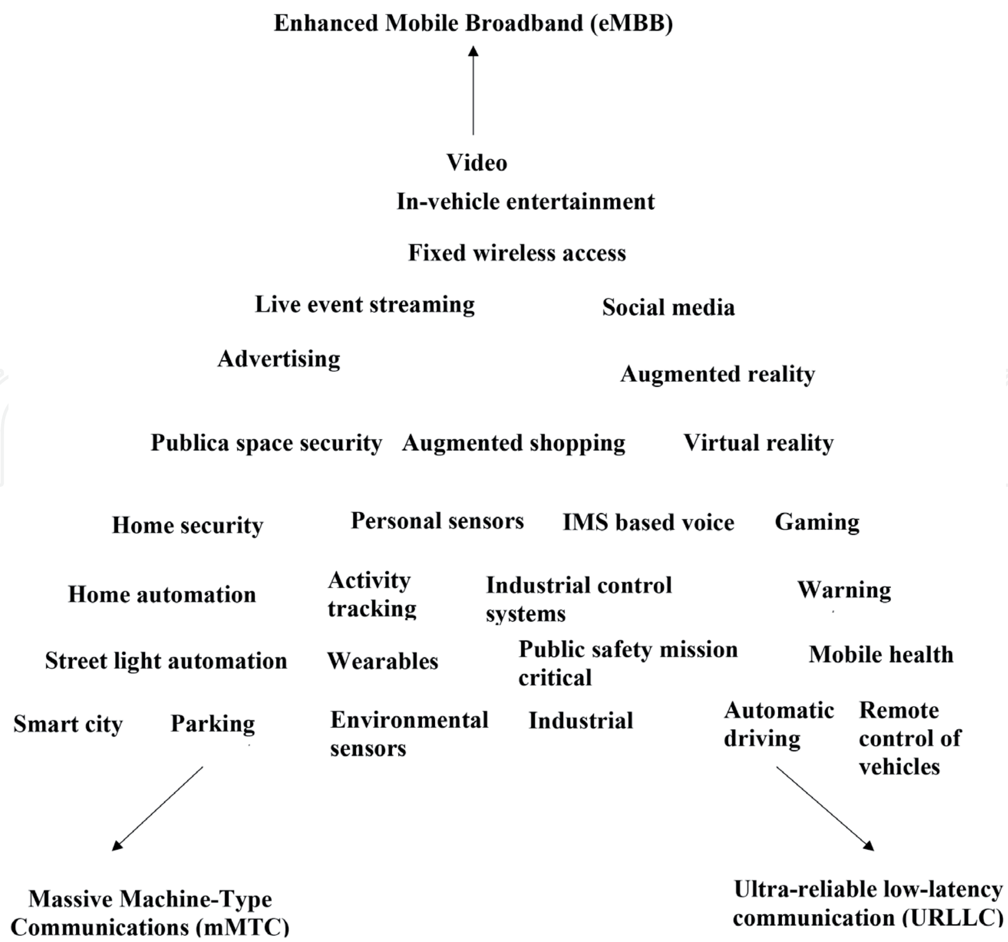

Figure 2.
Categorization of various use cases towards the three classes for 5G [9].

2 decades, and are now geared to shift to 5G coverage. So cellular operation, functioning at frequencies below 6 GHz, were suitable for systems designed for propagations up to 4G. However, the need for 5G cellular systems is to encompass much higher frequencies – starting from 500 MHz to 100 GHz. The BUET study [6], identified the following issues as the reason for wireless service in the buildings becoming increasingly challenging:

- the growth in individual data rate demand,
- the growth in the number of wireless devices, especially, BIoT devices,
- the use of BIoT devices at deeper locations in buildings, and
- the use of higher frequencies.

Ensuring proper radio coverage gets much more challenging, as the frequency increases, which is displayed in the three categories of use cases fit into the spectrum of 5G (**Figure 3**). Evidently, IoT based applications, typically, require low data rate and extended coverage, and thus, they suit lower frequencies. On the other hand, HD videos, VR, and other high data rate applications, require wide bandwidth and thus, high frequencies are used to facilitate eMBB. Similarly, URLLC applications fit in what ranges up to moderately high frequencies.

Building design, clearly plays an important role in wireless connectivity. Undoubtedly, existing buildings will have their own difficulties in addressing the connectivity issues, but proper attention to the related problems is of paramount

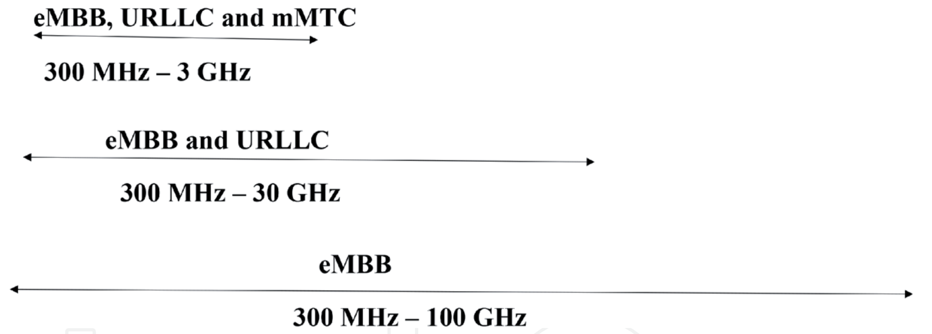

Figure 3.
Distribution of the categories of use cases within the Spectrum for 5G [9].

importance, for making new buildings suitable to this need, at the earliest design stages. This will ensure proper connectivity, as well as, user satisfaction, while addressing any adverse effects that this very propagation may have, on human well-being and health.

6.3 The building interior and internet connectivity

This section looks at internet connectivity, as it is affected by the design of interior spaces. Previous studies, have pointed out the role of penetration losses of various building materials, a quality that largely affects internet connectivity. Good connectivity can cause more homogenous data rate within buildings, thus operating at lower transmit power, conserving their batteries and affecting energy efficiency. An architect's consideration of wireless coverage at the design stage, can help improve coverage significantly. It is an established fact that signal coverage significantly depends on the nature of the space, and its bounding surfaces [3]. However, there is very little work done on establishing these qualities of building materials used in everyday construction.

Addressing this gap, penetration loss levels of some common building materials were determined, as part of the BUET study. The research also related the measured data with other existing information. Based on those measurements, taking into account the scope of architectural design, some guidelines were proposed for architectural intervention, to address the growing challenge of supporting wireless services in buildings. As an outcome of this research, a MATLAB program was developed, using radio propagation theories, which an architect can use during the design phase, to predetermine the impact of the proposed use of different penetration losses of building materials at various frequencies.

6.4 Effects on building design

Studies show that there is a sharp penetration loss at higher frequencies, in typical commercial buildings [10], which use infra-red reflective glass facades, in order to achieve energy efficiency. This will likely have grave consequences on internet connectivity, when the transmission source is outdoors. Propagation losses in interiors, either due to partitions, or space layout, are also considerable at these higher frequencies, and are dependent on the materials used in the layering of the spaces. Such consequences are likely to affect the 'smart' indicators within building interiors, which largely depend on M2M.

Surprisingly, the higher the operating frequency, the faster is the deterioration of radio frequencies, and so the distance, between the transmitting source and receiver in building interiors, needs to be controlled. Another important factor is the path that the wave has to travel between these two points. The higher the frequency, the less its ability to bend around obstacles, therefore requiring more direct visibility/paths between the points. This puts additional restrictions on the design of spaces, than previously encountered. Thus, clearly, both the building structure, and interior partitions can severely obstruct signal strength and internet connectivity, which will result in high propagation losses. This in turn will affect the battery life of the devices, which in itself is challenging under present options, as in many instances they are irreplaceable. Corrective measures like setting up an IBS (in-building solution) is often not feasible for small buildings or residences.

It is important for Architects, as well as interior designers, to be involved in the design and setting up of the wireless connection system, as space layout and the materials chosen, are all decisions taken by the Architect, and an understanding of these issues needs to be one of the considerations, that determine the ultimate design of the interior.

7. Suggested guidelines

This section summarizes the main guidelines suggested as a result of the BUET study [6]. The first of the guidelines concerned the choice of materials for internal partitions. Concrete and infrared reflective (IRR) glass exhibit high penetration losses. Loss due to concrete, takes place on account of it being a very heavy and dense material. Loss from IRR glass, which is not a heavy material, happens due to the reflection of a major part of the signal. On the other hand, plain glass and particle board exhibit low penetration losses, as they are light materials. Also, the higher the number of layers of a material used in a partition, and hence the thickness of the tested material, the higher was the measured penetration loss, with the loss increase being non-linear. In general, clear glass and particle board were found to be low penetration loss materials, while concrete and IRR glass was found to present high penetration losses at the frequencies they were tested for. For higher frequencies the loss would be likely to increase exponentially, pointing to the problems that would be encountered, in a shift from 4G to 5G transmission scenarios.

A stepped process of design was suggested for design to incorporate internet connectivity within buildings. Firstly, Selection of Options for Wireless Service, needs to be considered during building design, suitable for the particular wireless service option chosen. If the wireless signal from an outside cellular base station, seems sufficient for the wireless service in the building, then neither IBS nor Wi-Fi, Zigbee, WiGig, etc. are required. Then the architect should design, ensuring that the signal from outside can enter the building adequately, i.e. taking particular care of the building fenestration.

However, if an IBS is selected, the architect should design for better coverage from the IBS. If Wi-Fi, Zigbee, WiGig, etc. are selected, the installation locations of the sources may be pre-designed in the building, similar to designs produced for electric lights and plumbing. During the design phase, the architect may use indoor radio planning tools, and perform simulations, to check the potential wireless coverage, thereby making valuable adjustments in the architectural design of the building, to improve coverage and signal paths. A few indoor radio planning tools are currently available, like iBwave.

The second step would be to focus on connectivity issues related to architectural design. For any wireless service option, open planning inside the building can help signals propagate better, and pervade throughout the whole building, as the wireless coverage will be dependent on uninterrupted paths within the building. The following points were highlighted to ensure smooth paths and transmission:

i. Open plan can be used, especially, allowing more LOS links for the propagation of radio wave. The open plan concept for buildings is already popular, with less walls to cut off the area, an open plan gives the appearance of more space, which is further compounded by the abundance of light. Since in the case of open plan, the design attempts to avoid the use of real partitions, it allows the best propagation of the radio signal.

ii. Voids, corridors, room size, and so forth, can be incorporated to allow the geometry of space to enhance the openness.

iii. Larger room sizes can be designed for the given design brief.

iv. Long, unobstructed corridors will also allow smooth propagation

v. To improve the link between floors, vertical atriums or voids can be used

vi. Both hard and soft partitions can be used with careful design. An appropriate setting of hard and soft partitions can help allow the desired signal, and block any interference signals. However, this requires proper knowledge and record, of the penetration loss for various building materials, and its variation with increasing frequencies.

vii. The use of glass walls, within open plans can enhance desired signal power. Once the signal strengths are determined, low height walls or partitions can be used towards the desired signal, and high walls or partitions can be used towards any interference signal.

viii. Similarly, thin walls or partitions can be used towards the desired signal and thick walls or partitions can be used towards any interference signal.

ix. The position and orientation of hard or soft partitions can be carefully chosen, depending on the position of user devices, the desired signal source, and the interference signal source.

x. Multiple reflective walls, fringes or louvers may be used carefully to cause multipath signal bounce and get to the receiver.

The suggested guidelines have been presented for the consideration of an architect, but they also create awareness within other professionals, particularly RF Engineers, of the need to collaborate during the design phase, in order to bring relevant connectivity issues to the design board. The possible outcome of such collaboration and the architect's contribution can be summarized as follows.

a. It can be much easier to improve the wireless coverage at the design phase, while the RF engineers will require less time, effort and cost in their installation process.

b. The wireless resources, which are scarce, can be used more efficiently, thus contributing to energy efficiency.

c. The user data rate can be much higher, improving user satisfaction, as well as productivity.

d. IoT devices at deeper locations in buildings can be operable.

e. IoT devices will require less transmit power in uplink and thus, save battery power and meet the requirement of a very long lifetime.

f. The undesired spillage of signal outside the building can be reduced.

8. Covid pandemic issues and other conflicting needs

The recent global pandemic of Covid-19 has also brought focused attention towards sick building syndromes, or SBS. This phenomenon has been a concern for the past five decades, ever since the widespread acceptance of fully air-conditioned buildings became the preferred typology of built spaces, particularly in the thermally challenged situations found in the tropics. The Covid pandemic resulted in the need to maintain social distancing, and in trying to increase the rate at which interior, potentially infected air, is replaced by purer and infection-free outdoor air. Both these requirements have necessitated a shift in the ways in which interiors are conceived.

As the plan layout of spaces is a vital element in maintaining internet connectivity between the transmitting source and receivers, which may be fixed or moveable, these new considerations will also impact the quality of internet connectivity, and needs to be given due thought hand in hand, in order to ensure human health requirements. When more compartmentalization is the need, for isolating infections, and protecting the occupants, the positioning of partitions, their materials and design, all impact the efficiency of internet connectivity.

Green and sustainable planners also advocate compactness in planning a new development, in order to reduce traffic loads, which can be a valuable energy saver. Compactness also allows increased pedestrian movement and biking between destinations, again an active energy efficient measure, which also promotes health benefits from exercise, an added sustainability feature. Again, this measure may contradict the need to create greater distancing between occupants, a requirement vital to control pandemic spreads. The density of neighborhoods is also likely to affect the internet connectivity issue, creating greater obstructions within smaller pathways, affecting the strength of the signals.

The strongly synergistic connection, between the effects of each and every consideration on suitability, regarding physical distancing and/or compartmentalization, is a phenomenon that is encountered time and again, whenever any requirement is compared to others. For instance, the need for avoiding solar exposure may result in infra-red reflective glass facades, but this conflicts with the need to have uninterrupted internet receptivity within the interiors, as mentioned above.

Much research is now required to address the conflicts between the different needs that a building is designed to serve, whether they be thermal comfort, visual comfort, privacy, security, health and air quality needs, and even inclusivity. It is now becoming vital for designers to address the various requirements, and make intelligent and considered choices regarding each, understanding what and the extent of compromises being made for different design decisions, and whether they are potentially harmful or not. The issue of the health hazards of RF transmissions is also of paramount concern at the moment and needs extensive research.

9. Conclusion

The wireless connectivity, in a building, is an important aspect of today's lifestyles, without which it is impossible to function and achieve sustainability. This is because it improves the life of building users greatly, while only consuming nominal energy, making it a key ingredient of green architecture. Thus, it is essentially providing great services, without destroying fossil fuels, and protecting the future world. And this is being demonstrated increasingly, given the work from home scenario found recently during the Covid pandemic. It is unclear how well the World could have handled the lock-down situation, had internet not reached its present development. This makes it of vital importance in the present World, to ensure the provision of seamless internet connectivity, for even the basics of life to function efficiently.

The discussion has related the objectives of the UN SDGs to the issue of having internet access and connectivity, and their intrinsic link to the architecture of spaces. It is difficult in the present times to think of sustainability in the absence of seamless internet connectivity within building interiors. This combines the expertise of multi-disciplinary teams of Architects and RF Engineers.

From a recent research conducted at BUET relating these disciplines, the various options for wireless services have been listed, particularly since the services are increasing their data rate to 5G levels in the near future. Clearly building interiors need to be designed with focus on the issues of seamless propagation of RF waves. The different architectural measures that can be adopted to make this possible have been mentioned here. The geometry of spaces, their spatial flow and materials, their partitions, and openings, all contribute to the flow of internet connectivity. What remains still unaddressed is the matter of the health and safety issues related to 5G transmission scenarios, which it has been suggested deserves special attention in future research.

This paper has brought out the importance of the different disciplines to collaborate in the design of the environment, in order to ensure seamless and safe transmission of internet connectivity. The collaboration needs to begin at the design phase, so that proper decisions are implemented with an understanding of the consequences holistically. Each of the professionals are experts in their own spheres, but they need to make each other aware of the needs which will best serve the built environment, and help improve user satisfaction, while reducing energy wastage. The participatory approach is the only acceptable way forward.

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